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RED OXIDE OF COPPER AS A SEED FUNGICIDE FOR COMBATING DAMPING-OFF BY SEED TREATMENT

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RED OXIDE OF COPPER AS A DUST FUNGICIDE FOR COMBATING DAMPING-OFF BY SEED TREATMENT

JAMES G. HORSFALL[1]

ABSTRACT

In 15 duplicate tests red oxide of copper, cuprous oxide (cuprite), used as a seed treatment for tomatoes, eggplants, peppers, and certain other vegetables seemed to compare favorably with previously recommended materials for increasing stands and for combating damping-off in greenhouse flats caused by *Pythium ultimum*. It appeared to be somewhat less effective than copper sulfate soak in combating the post-emergence phase of damping-off, however.

On smooth-seeded plants like eggplants, cuprous oxide is especially desirable as a fungicide because of its adhesiveness, which is two and one-half times as great as that of copper sulfate monohydrate on tomato seeds. On a basis of copper content red oxide adheres seven times as well as copper sulfate monohydrate.

This extraordinary adhesiveness suggests the material as a foliage fungicide, a possibility that remains to be tested thoroly.

Cupric oxide (black) has but little fungicidal value when used as a seed treatment.

INTRODUCTION

The problem of obtaining a stand of vegetable seedlings and of combating damping-off looms large in the eyes of commercial greenhouse men, since frequently the disease means the difference between profit and loss to them. Considerable research effort has been expended to alleviate the difficulty and yet damping-off is still of major importance to greenhouse operators. Steaming the soil has long been advocated for damping-off control, but several factors have functioned to prevent the use of the method in many instances. The most recent contribution to the control of damping-off in the plant bed has

[1]The writer desires to express his thanks to Messrs. J. E. Bradley and Chas. Snell of the Quaker Maid Company for many courtesies extended during this investigation.

been that of Alexander, Young, and Kiger (1)[2] who recommend that a formaldehyde dust be applied to the soil at seeding time. This latter method is subject to one of the difficulties inherent in the use of steam, *viz.*, the danger of recontamination as a result of carelessness on the part of laborers, who do not appreciate the fact that the sterilizing process is only transitory and not lasting in its action.

Bearing in mind the need for a fungicidal agent that would be continuously active, the writer approached the problem several years ago thru the seed treatment gateway. Soil treatment also has been used, but the factor of plant injury has not permitted as much progress in that direction. Seed treatments are of most value for controlling the pre-emergence phase of damping-off. Their chief weakness, of course, is that they fail sometimes to protect the emerged seedlings fully against the inroads of pathogenic organisms. However, except under conditions more than usually favorable to damping-off, they are fairly satisfactory even for that purpose. Seed treatments appeal to the growers too, because they are easy and harmless to use and because they are cheap.

Among other results from the investigation of damping-off at this Station that showing the efficacy of red oxide of copper, or cuprite, as a seed treatment fungicide seems worth presenting now. In an earlier paper (9, page 3), the possibility of the material was mentioned by saying that, "Increased stands have been obtained also on a small scale by dusting seeds with cuprous oxide." During this study the value of the material has been demonstrated repeatedly, both experimentally and by commercial greenhouse men. It was chosen for further trial after a survey of most of the copper dusts that might be useful. Its promise lay in its insolubility, efficacy, and remarkable adherence when used as a dust. A part of the data obtained with red oxide of copper are recorded here in order to present some of the possibilities of the material as a useful fungicide, especially as a dust seed treatment to be used by greenhouse men for combating damping-off.

An examination of the literature reveals that cuprous oxide has been used occasionally as a fungicide, but its possibilities do not appear to have been recognized widely. Atkins (3) used red oxide of copper in a paint to prevent the destruction of fishing nets by molds. Verwoerd (13) obtained control of flag smut of wheat by treating the

[2]Refers to Literature Cited, page 25.

seed with the material. Petit (11), however, decided from his trials that the copper oxides were not as satisfactory as certain other copper compounds, notably chloride, for controlling bunt of wheat by seed treatment. Gassner (5) used a solution of ammoniacal copper oxide for wheat bunt, but he failed to mention the form of copper oxide used. Copper hydroxide was advocated by Hooker (8) as a substitute for bordeaux mixture, and Heald (6) found that the same material was valuable as a seed treatment for bunt of wheat. Copper oxide (mostly black) is widely used to make a non-fouling paint to discourage plants and animals from growing on the bottoms of boats.

DAMPING-OFF AS A DISEASE

In presenting the data obtained from damping-off studies, it is desirable to emphasize the true nature of the disease. A widespread notion prevails that damping-off is due entirely to excessive soil wetness. As a matter of fact excessive wetness is only a secondary factor that accentuates the activity of soil-borne molds that are responsible primarily for the disease. Microscopic examination of infected plants reveals that the tissues have been riddled by molds, mostly by the water mold known as *Pythium ultimum* Trow. Inoculation with these molds will reproduce the disease.

In the presence of the fungus lies the explanation to the control of the disease by chemical treatment. Obviously, a chemical applied to the seed can have no effect upon soil wetness by varying the use of the hose or the sprinkling pot, and yet it will aid in controlling the disease. The explanation, in part at least, is that the chemical put into the soil on each seed poisons the molds that are lying in wait ready to attack the seedling at the first opportunity, which is usually presented when the soil becomes too wet.

It is necessary to point out here also that damping-off occurs before the seedling comes up as well as afterward. In fact, many of the poor stands of vegetable seedlings may be easily explained by the fact that the seedlings damped off before they were able to get above the soil line. To simplify the text of this paper, two terms are used—pre-emergence and post-emergence damping-off.

MATERIALS AND METHODS

The experimental technic used in these damping-off studies has been described fully in a recent publication (10), so that it need not

be repeated here. Supposedly healthy seed was used in all cases. This seed was measured with a 30-mm shell vial into equal lots of 1,300 to 2,000 seeds each, the actual number being determined by several counts. The use of this large number of seeds was deemed necessary in order to simulate the crowded conditions in the flat that favor damping-off. They were sown in ordinary greenhouse flats or trays in greenhouse soil naturally contaminated with *Pythium*

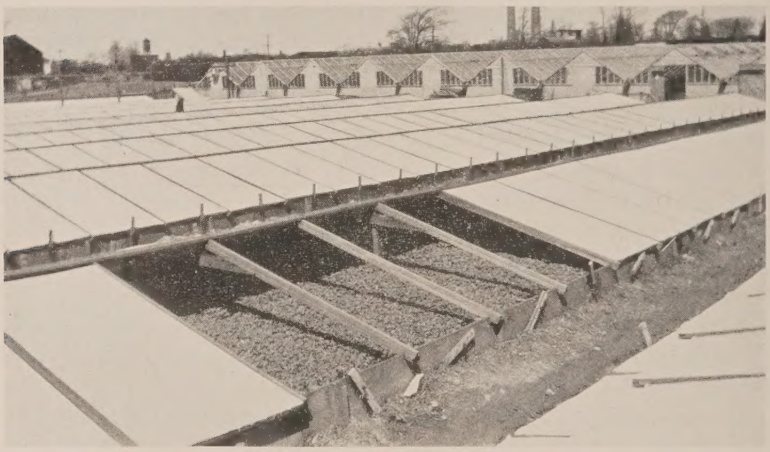

FIG. 1.—A LARGE COMMERCIAL PLANT-GROWING UNIT OF GREENHOUSES AND COLD FRAMES USED FOR PRODUCING TOMATO PLANTS IN NEW YORK STATE. Materials proposed for combating damping-off are always tested in commercial greenhouses like these before they are finally submitted to growers.

ultimum Trow. The seeds were treated by shaking in a 250-ml Erlenmeyer flask with an excess of dust which was removed afterwards with a 20-mesh screen. Most of the tests were conducted in the Station greenhouses, but the results were checked freely in commercial greenhouses, such as that shown in Fig. 1, where facilities are available for producing 1,500,000 plants annually.

After emergence had been completed and at the time the first true leaf was about grown, counts were made of the seedlings that emerged (the stand) as well as those that were diseased. The latter included seedlings with spots on their roots as well as those that actually damped-off. From these figures could be calculated the per-

centage of pre-emergence disease (seeds rotted by soil organisms) and the percentage of post-emergence disease. Finally, the value of each treatment in reducing each phase of the disease was expressed as an index of disease,[3] based on the check in each test. It was calculated by dividing the percentage of disease in the treated by the percentage of disease in the untreated flats and multiplying by 100. In making this calculation the checks are assumed to represent the maximum, or 100 per cent, of the possible disease expression under the conditions of the test in question. Thus, in obtaining the relative value of a treatment in any one test, its incidence of disease is divided by the incidence of disease in the check and multiplied by 100, giving an "index of disease" for the treatment. In this way, the lower the index number, the better the treatment for combating the disease. An average of these index numbers for any one treatment gives a more precise picture than a mere average of the incidences of infection for the separate trials, because it compensates somewhat for environmental differences obtaining at the time of the various tests.

EXPERIMENTAL RESULTS

COMPARISON OF EFFICIENCIES OF RED OXIDE OF COPPER AND STANDARD COPPER FUNGICIDES

As standards, the red oxide of copper was compared in 15 duplicate tests with a check (untreated), directly with the soak and with copper carbonate dust five and two times, respectively. The data from these tests appear in Table 1. In view of the scarcity of direct comparisons between the new material and the old standards, however, the data on the latter were brought forward from the previous publications (9 and 10) and added in when the means were calculated. The inclusion of the other data in the means was done in order to reduce the error inherent in only a few comparisons. Furthermore, it was feasible, since in each case the materials were referred back to checks, and it was particularly desirable in view of the large number of replications, 15, of the oxide treatment.

[3]In previous publications the writer has labeled this number "average percentage of the check." That expression, however, is inadequate to express the concepts involved. Index of disease seems to be a more logical term since it emphasizes the reduction from the check in the incidence of disease.

TABLE 1.—COMPARISON OF RED OXIDE OF COPPER WITH COPPER SULFATE SOAK AND OFF OF TOMATOES IN SOIL NATURALLY

No. of experiment	Date of record	Check (untreated)			Dusted with red oxide of copper				
		Emergence, per cent	Disease		Emergence, per cent	Disease			
			Pre-emergence, per cent	Post-emergence, per cent		Pre-emergence		Post-emergence	
						Per cent	Index	Per cent	Index
1a	Mar. 24,	85.0	15.0	19.7	98.1	1.9		—	
1b	1930	79.6	20.4	24.8	—	—		—	
Av.		82.3	17.7	22.3	98.1	1.9	10.7	—	—
2a	Oct. 24,	36.2	63.8	60.0	73.1	26.9		13.5	
2b	1930	41.5	58.4	55.5	73.1	26.9		32.5	
Av.		38.9	61.1	57.8	73.1	26.9	44.0	23.0	39.8
3a	Nov. 14,	46.8	53.2	46.5	79.6	20.4		38.0	
3b	1930	45.3	54.6	77.0	79.9	20.0		25.0	
Av.		46.1	53.9	61.8	79.8	20.2	37.5	31.5	51.0
4a	May 23,	87.8	12.2	52.0	95.9	4.1		7.5	
4b	1931	79.3	20.7	49.0	84.5	15.5		11.5	
Av.		83.6	16.5	50.5	90.2	9.8	59.4	9.5	18.8
5a	Nov. 25,	39.4	60.6	61.5	99.8	0.2		13.0	
5b	1931	67.6	33.4	44.0	91.5	8.4		15.0	
Av.		53.5	46.5	52.8	95.7	4.3	9.2	14.0	26.5
6a	Nov. 28,	64.8	35.2	58.0	77.7	22.3		18.0	
6b	1931	67.3	32.6	53.5	99.7	0.3		22.0	
Av.		66.1	33.9	55.8	88.7	11.3	33.3	20.0	35.8
7a	Feb. 4,	59.9	40.0	56.5	90.9	9.1		17.0	
7b	1932	67.0	33.0	51.0	88.6	11.3		13.5	
Av.		63.5	36.5	53.8	89.8	10.2	27.9	15.3	28.4
8a	Feb. 4,	73.4	26.6	49.0	95.9	4.1		19.5	
8b	1932	64.0	36.0	53.5	94.6	5.3		25.0	
Av.		68.7	31.3	51.3	95.3	4.7	15.0	22.3	43.5
9a	Feb. 5,	58.9	41.1	47.0	85.0	15.0		22.0	
9b	1932	63.2	36.7	43.0	83.4	16.6		20.0	
Av.		61.1	38.9	45.0	84.2	15.8	40.6	21.0	46.7
10a	Feb. 9,	68.2	31.8	47.0	97.1	2.9		9.0	
10b	1932	70.2	29.8	48.5	90.9	9.1		13.5	
Av.		69.2	30.8	47.8	94.0	6.0	19.5	11.3	23.6
11a	Feb. 29,	77.8	22.2	39.5	95.4	4.6		13.5	
11b	1932	72.9	27.0	59.0	87.2	12.8		17.0	
Av.		754.	24.6	49.3	91.3	8.7	35.4	15.3	31.0
12a	Mar. 3,	77.2	22.8	46.0	84.2	15.8		13.5	
12b	1932	6.46	35.4	54.0	88.0	12.0		11.0	
Av.		70.9	29.1	50.0	86.1	13.9	47.8	12.3	24.6
13a	Mar. 10,	85.3	14.7	38.5	82.5	17.5		16.5	
13b	1932	85.1	14.9	45.0	94.8	6.1		19.5	
Av.		85.2	14.8	41.6	88.7	11.3	76.4	18.0	43.3
14a	Mar. 16,	8.10	19.0	50.5	83.4	16.6		16.5	
14b	1932	78.2	21.8	52.5	89.1	10.9		22.0	
Av.		79.6	20.4	51.5	86.3	13.7	67.2	19.3	37.5
15a	Apr. 4,	71.1	28.9	43.0	73.9	26.1		15.0	
15b	1932	69.1	31.8	45.5	81.1	18.9		19.5	
Av.		70.1	29.9	44.3	77.5	22.5	75.3	17.3	39.1
16a	Apr. 5,	54.3	45.7	29.5	91.5	8.5		16.5	
16b	1932	50.1	49.9	59.0	85.4	14.5		11.0	
Av.		52.2	47.8	44.3	88.5	11.5	24.1	13.8	31.2
Grand average							38.96*		34.72*

*Average weighted according to the index of disease in each separate test, thus compensating
†Data from Bulletin No. 586 and Technical Bulletin No. 198 of this Station included in these averages.

COPPER CARBONATE DUST AS A SEED TREATMENT IN REDUCING THE INCIDENCE OF DAMPING-CONTAMINATED WITH *Pythium ultimum*.

SOAKED 1 HR. IN COPPER SULFATE SOLUTION					DUSTED WITH COPPER CARBONATE				
Emergence, per cent	Disease				Emergence, per cent	Disease			
	Pre-emergence		Post-emergence			Pre-emergence		Post-emergence	
	Per cent	Index	Per cent	Index		Per cent	Index	Per cent	Index
—	—		—		—	—		—	
—	—		—		—	—		—	
—	—	—	—	—	—	—	—	—	—
—	—		—		—	—		—	
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—	—		—		—	—		—	
—	—		—		—	—		—	
—	—	—	—	—	—	—	—	—	—
90.1	9.9		19.5		—	—		—	
82.6	17.4		17.0		—	—		—	
86.4	13.6	82.4	18.3	36.2	—	—	—	—	—
—	—		—		—	—		—	
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—	—		—		—	—		—	
—	—	—	—	—	—	—	—	—	—
88.3	11.7		7.5		66.9	33.1		18.5	
92.5	7.5		6.0		70.3	29.7		21.0	
90.4	9.6	39.0	6.8	13.8	68.6	31.4	145.4	19.8	40.1
84.2	15.8		16.5		—	—		—	
88.4	11.6		14.0		—	—		—	
86.3	13.7	47.1	15.3	30.6	—	—	—	—	—
—	—		—		—	—		—	
—	—		—		—	—		—	
—	—	—	—	—	—	—	—	—	—
—	—		—		67.1	32.9		25.0	
—	—		—		82.2	17.8		35.5	
—	—	—	—	—	74.7	25.3	124.1	30.3	58.8
90.1	9.9		13.5		—	—		—	
88.4	11.5		9.5		—	—		—	
89.3	10.7	35.8	11.5	26.0	—	—	—	—	—
86.0	14.0		14.0		—	—		—	
85.9	14.1		11.0		—	—		—	
86.0	14.0	29.2	12.5	38.2	—	—	—	—	—
		48.55*†		22.77*†			83.51*†		55.07*†

somewhat for uncontrolled variables like environment.

The effect of these seed treatments on stand are shown graphically in Fig. 2 where they are arranged in ascending order of value as follows: Copper carbonate dust, copper sulfate soak, red oxide of copper dust, and copper sulfate monohydrate dust. The stand in-

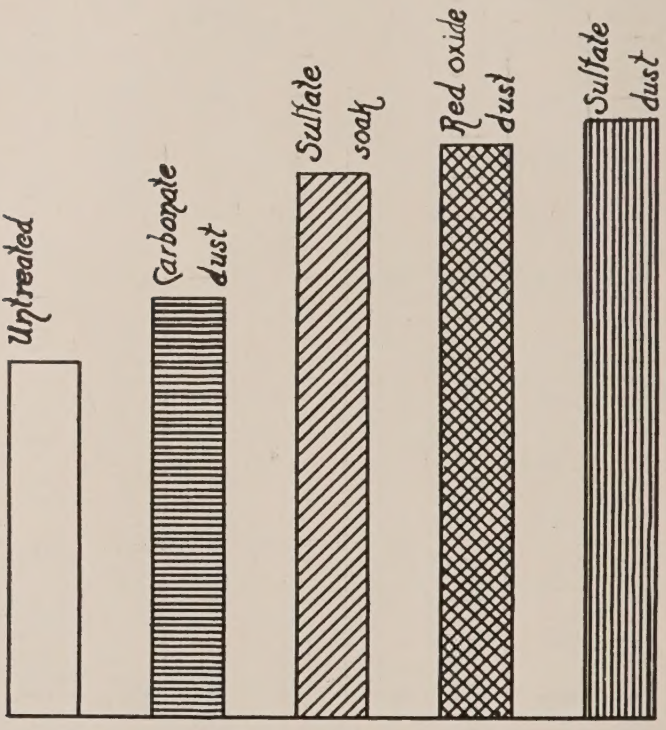

FIG. 2.—INCREASE IN STAND RELATIVE TO THE CHECK AS A RESULT OF TREATING TOMATO SEED WITH COPPER SULFATE SOAK, COPPER SULFATE DUST, COPPER CARBONATE DUST, AND RED OXIDE OF COPPER DUST.

These increases computed from indices of disease shown in Table 2.

creases relative to the check as shown in Fig. 2 are computed for the sake of uniformity from the weighted average index of disease given in Table 2 and shown graphically in Fig. 4. It should be noted that the red oxide in its ability to increase stands lies intermediate between the soak and the dust forms of copper sulfate. A photographic comparison of seedlings from seeds treated with red oxide of copper

and seedlings from untreated seed appears in Fig. 3 where the differences in stand are clearly shown.

In order to be sure of any difference between two treatments, the data were calculated according to a mathematical formula previously mentioned (10). This mathematical comparison of the figures ap-

FIG. 3.—INCREASE IN STAND OF TOMATO SEEDLINGS RESULTING FROM TREATING THE SEED WITH RED OXIDE OF COPPER.
A, a flat of 788 seedlings from 2,000 untreated seeds; B, a flat of 1,960 seedlings from 2,000 treated seeds. (See experiment No. 5 in Table 1.)

pears in Table 2 where the weighted averages for the index of disease are shown. The averages for the copper sulfate monohydrate were taken directly from the publication dealing with that material (10), since no additional tests with it were made.

From Table 2 it is apparent that red oxide dust controlled both phases of damping-off significantly better than the carbonate dust. It was better than the soak but poorer than the monohydrate dust for pre-emergence disease control, altho not significantly so in either case. The soak was significantly better than the red oxide for post-emergence control, altho the latter was not significantly superior to the monohydrate dust for this phase of the malady. Recalculat-

TABLE 2.—BIOMETRICAL COMPARISON OF THE INDICES OF DISEASE OBTAINED WITH RED OXIDE OF COPPER DUST, COPPER SULFATE SOAK, COPPER CARBONATE DUST, AND COPPER SULFATE MONOHYDRATE DUST AS SEED TREATMENTS FOR COMBATING DAMPING-OFF OF TOMATOES IN SOIL NATURALLY CONTAMINATED WITH *Pythium ultimum*.

MATERIAL	MEAN*	ERROR OF MEAN	DIFFERENCES BETWEEN MATERIAL AND								
			Copper sulfate soak			Copper sulfate monohydrate dust			Copper carbonate dust		
			D	E_d	$\frac{D}{E_d}$	D	E_d	$\frac{D}{E_d}$	D	E_d	$\frac{D}{E_d}$
Pre-emergence Disease											
Red oxide of copper dust	38.96	3.56	9.59	6.07	1.58	5.51	4.68	1.18	44.55	8.86	5.03
Copper sulfate soak	48.55	4.92	——	——	——	15.10	5.78	2.61	34.96	9.49	3.68
Copper sulfate monohydrate dust†	33.45	3.07	15.10	5.78	2.61	——	——	——	50.06	8.66	5.78
Copper carbonate dust	83.51	8.11	34.96	9.49	3.68	50.06	8.66	5.78	——	——	——
Post-emergence Disease											
Red oxide of copper dust	34.72	1.68	11.95	2.54	4.70	7.81	6.14	1.27	20.35	5.14	3.96
Copper sulfate soak	22.77	1.91	——	——	——	19.76	6.21	3.18	32.30	5.22	6.19
Copper sulfate monohydrate dust†	42.53	5.91	19.76	6.21	3.18	——	——	——	12.54	7.65	1.64
Copper carbonate dust	55.07	4.86	32.30	5.22	6.19	12.54	7.65	1.64	——	——	——

*Mean is weighted according to the index of disease obtained in each separate test.
†Data brought forward from Technical Bulletin No. 198 of this Station.

ing the averages for the soak and the carbonate dust on the basis of a larger number of tests than given previously does not alter them materially for comparison with the averages (10) for monohydrate dust, which were unaltered by additional testing. One exception seems to be that the use of the additional replications for the soak so

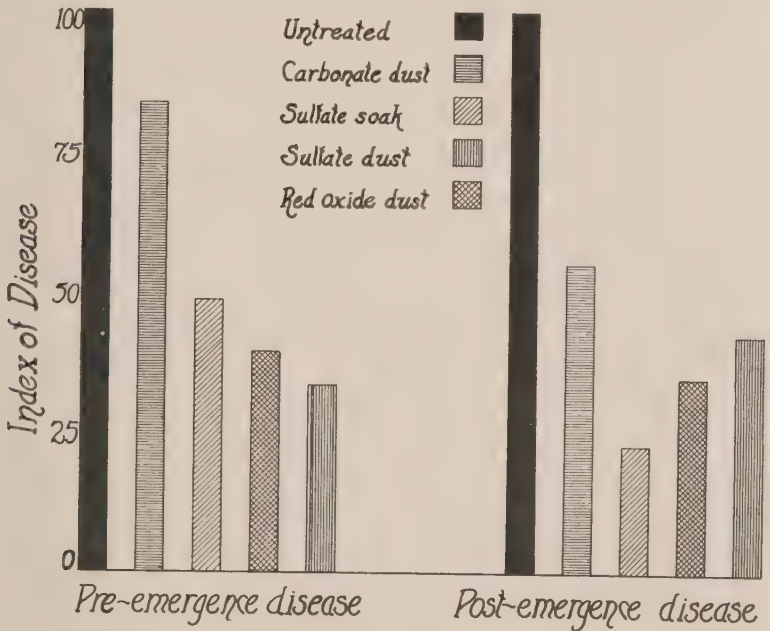

FIG. 4.—COMPARISON BETWEEN RED OXIDE OF COPPER DUST, COPPER SULFATE SOAK, COPPER SULFATE MONOHYDRATE DUST, AND COPPER CARBONATE DUST AS SEED TREATMENTS FOR COMBATING DAMPING-OFF OF TOMATOES IN GREENHOUSE SOIL.

reduced the probable error of the mean for post-emergence disease control that the difference between the soak and the monohydrate dust was rendered significant or practically so.

The data on disease control from Table 2 are shown in the graph in Fig. 4. This graph is somewhat more complicated than that shown in Fig. 2 because it gives the actual disease control—the index of pre-emergence disease on the left side and the index of post-emergence disease on the right side. The left half of the graph is of technical significance only and was prepared for comparison with a similar graph presented in the recent publication (10) on copper sulfate

TABLE 3.—COMPARISON OF RED OXIDE OF COPPER WITH COPPER SULFATE SOAK AS A SEED TREATMENT FOR COMBATING DAMPING-OFF OF EGGPLANTS, PEPPERS, AND CABBAGE IN SOIL NATURALLY CONTAMINATED WITH *Pythium ultimum*.

No. of experiment	Date of record	Check (untreated)			Dusted with red oxide of copper					Soaked 1 hour in copper sulfate solution				
			Disease			Disease					Disease			
						Pre-emergence		Post-emergence			Pre-emergence		Post-emergence	
		Emergence, per cent	Pre-emergence, per cent	Post-emergence, per cent	Emergence, per cent	Per cent	Index	Per cent	Index	Emergence, per cent	Per cent	Index	Per cent	Index
						Eggplants								
1a	Nov. 27,	52.5	47.5	21.7	66.5	33.5		26.5		—	—		—	
1b	1931	56.0	44.0	25.1	65.9	34.1		33.5		—	—		—	
Av....		54.3	45.7	23.4	66.2	33.8	74.0	30.0	128.2	—	—	—	—	—
2a	Feb. 23,	1.4	98.6	73.7	49.4	50.6		29.5		—	—		—	
2b	1932	3.7	96.3	57.7	42.1	57.9		23.0		—	—		—	
Av....		2.6	97.8	65.7	45.8	54.2	55.4	26.3	41.0	—	—	—	—	—
3a	Feb. 18,	25.7	74.3	74.0	81.9	18.1		22.0		—	—		—	
3b	1932	21.3	78.7	71.0	56.0	44.0		30.0		—	—		—	
Av....		23.5	76.5	72.5	69.0	31.0	40.5	26.0	35.9	—	—	—	—	—
4*a	Mar. 4,	19.1	80.9	—	60.1	39.9		—		—	—		—	
4b	1932	43.4	56.6	—	60.1	39.9		—		—	—		—	
Av....		31.3	68.7	—	60.1	39.9	58.1	—	—	—	—	—	—	—

5a	Mar. 4,	30.8	69.2	—	41.8	58.2		—		—	—		—	
5b	1932	49.8	50.2	—	57.4	42.6		—		—	—		—	
5c		50.0	50.0	—	64.8	35.2		—		—	—		—	
Av....		42.9	57.1	—	54.7	45.3	79.3	—	—	—	—	—	—	—
6	Mar. 4, 1932	21.8	78.2	—	43.8	56.2	71.9	—	—	—	—	—	—	—
7a	Apr. 27,	39.8	60.2	36.5	52.0	48.0		44.5		53.9	46.1		27.0	
7b	1932	45.2	54.8	28.0	58.1	41.9		40.0		48.5	51.5		28.5	
Av....		42.5	57.5	32.3	55.1	44.9	78.1	42.3	131.0	51.2	48.8	84.9	27.8	86.1
Grand Av.		—	68.8	48.5	—	43.6	65.3	31.2	83.8	51.2	48.8	84.9	27.8	86.1
Peppers														
1a	Dec. 8,	34.1	65.9	33.0	78.5	21.5		10.5		—	—		—	
1b	1931	33.5	66.5	36.5	77.1	22.9		12.0		—	—		—	
Av....		33.8	66.2	34.8	77.8	22.2	33.5	11.3	32.5	—	—	—	—	—
2a	Mar. 4,	24.6	75.4	—	42.8	57.2		—		—	—		—	
2b	1932	28.0	72.0	—	47.4	52.6		—		—	—		—	
Av....		26.3	73.7	—	45.1	54.9	74.5	—	—	—	—	—	—	—
Grand Av.		—	70.0	34.8	—	28.6	54.0	11.3	32.5	—	—	—	—	—
Cabbages														
1a	Nov. 20,	39.4	60.6	32.5	57.6	42.4		30.0		—	—		—	
1b	1931	44.4	55.6	45.0	46.6	53.4		33.5		—	—		—	
Av....		41.9	58.1	38.8	52.1	47.9	82.4	31.8	82.0	—	—	—	—	—

*This test was made in a commercial house. The grower remarked that he had not seen as good a stand of eggplant seedlings in years as he obtained by treating the seed with red oxide of copper.

monohydrate. In reality it is only another way of expressing the effect of red oxide of copper and the other materials on emergence of tomato seedlings.

The right-hand portion of the graph is of special interest in showing that the red oxide was intermediate between the copper sulfate soak and dust for controlling damping-off of emerged seedlings. The red oxide thus appears to be a more satisfactory double-purpose material than either of the two standards, since it seemed about equally satisfactory for increasing stands as for curtailing the post-emergence damping-off. The copper sulfate soak is superior to red oxide dust for decreasing post-emergence disease, but inferior for increasing stands. Copper sulfate monohydrate dust, on the other hand, is slightly superior for increasing stands, but inferior to the red oxide dust for controlling the post-emergence phase.

Altho red oxide of copper has not been tried extensively on vegetables other than tomatoes, the few data obtained will be presented as illustrations of its possibilities. Eggplant, *Solanum melongena*, was used as an experimental subject for several tests because of its apparently high susceptibility to damping-off. Growers, in general, complain more about damage from damping-off in their eggplant seedlings than in their tomatoes. The data obtained on eggplant, variety Black Beauty; peppers (*Capsicum annuum*), variety Harris' Early Giant; and cabbage (*Brassica oleracea*), variety Einkhuizen Glory, appear in Table 3.

From Table 3 it is apparent that red oxide of copper increased the stands and reduced the incidence of damping-off of eggplants, peppers, and cabbage. It is with the smooth seeds of these plants that red oxide of copper finds its special application as a dust fungicide since copper sulfate monohydrate does not adhere as well to these smooth seeds as it does to tomato seeds which are hairy. In fact, the red oxide sticks so well that the seeds become brick red in color.

EFFECT OF DILUTION UPON EFFICIENCY OF RED OXIDE OF COPPER

Since it was difficult to determine the minimum effective dosage of the material by weighing it out for the small lots of seed used, this question was studied by diluting the material with an inert filler, talc in this case. Accordingly, chemically pure red oxide of copper was diluted with talc to varying degrees and applied to tomato seeds in excess as usual. The results in combating damping-off are given in Table 4.

TABLE 4.—EFFECT OF DILUTION WITH TALC UPON EFFECTIVENESS OF RED OXIDE OF COPPER AS A SEED TREATMENT FOR COMBATING DAMPING-OFF OF TOMATOES IN NATURALLY-CONTAMINATED SOIL.

TREATMENT	DILUTION, PER CENT	NOVEMBER 28, 1931					MARCH 10, 1932				
		Emergence, Per cent	Disease				Emergence, Per cent	Disease			
			Pre-emergence		Post-emergence			Pre-emergence		Post-emergence	
			Per cent	Index	Per cent	Index		Per cent	Index	Per cent	Index
Check (untreated)	00.0	85.3	14.7		38.5		58.0	42.0		64.8	
Check (untreated)	00.0	85.1	14.9		45.0		53.5	46.5		69.3	
Av.		85.2	14.8	00.0	41.8	00.0	55.7	44.3	00.0	66.1	00.0
Seeds dusted	2	79.5	20.5		25.5		62.6	37.4		41.5	
Seeds dusted	2	86.3	13.7		27.0		73.2	26.8		50.0	
Av.		82.9	17.1	115.5	26.3	62.9	67.9	32.1	72.5	45.8	69.3
Seeds dusted	5	78.9	21.1		23.0		87.5	12.5		37.5	
Seeds dusted	5	90.3	9.7		21.5		69.1	30.9		30.0	
Av.		84.6	15.4	104.1	22.3	53.3	78.3	21.7	49.0	32.8	49.6
Seeds dusted	10	79.0	21.0		18.0		89.2	10.8		28.0	
Seeds dusted	10	72.1	27.9		26.0		81.6	18.4		29.0	
Av.		75.5	24.5	165.5	22.0	52.6	85.4	14.6	33.0	28.5	43.1
Seeds dusted	25	86.9	13.1		18.5		95.2	4.8		22.0	
Seeds dusted	25	90.9	9.1		16.0		79.9	20.1		21.0	
Av.		88.9	11.1	75.0	17.3	41.4	87.5	12.5	28.2	21.5	32.5
Seeds dusted	50	80.1	19.9		15.0		95.1	4.9		20.0	
Seeds dusted	50	96.8	3.2		13.0		87.0	13.0		23.5	
Av.		88.5	11.5	77.7	14.0	33.5	91.5	8.5	19.2	22.8	34.5
Seeds dusted	100	82.5	17.5		16.5		77.7	22.3		18.0	
Seeds dusted	100	94.8	5.2		19.5		99.7	.3		22.0	
Av.		88.6	11.4	77.0	18.0	43.1	88.7	11.3	25.1	20.0	30.3

Altho the disease was not severe enough on the checks in the first test shown in Table 4 to give good differentiation between the dilutions, yet the data from the second test indicate that red oxide of copper may be diluted safely to 25 per cent in talc without altering materially its fungicidal efficiency. Further trials might have indicated that an even greater dilution was possible. Stated in another way, these data indicate that approximately four times as much of the material adhered to the seed as is required for its optimum effect in damping-off control. This conclusion presupposes, however, equal adherence of the material and the filler, and the same results with different fillers, points which have not yet been settled.

ADHERENCE OF RED OXIDE OF COPPER TO TOMATO SEEDS

Since red oxide of copper seemed to stick so well to smooth seeds, as well as to tomato seeds, an attempt was made to determine how much of the chemical in the absence of filler would adhere to a known quantity of seed. Accordingly, five lots of John Baer tomato seed (measured as for sowing) were counted, weighed, and treated in the usual manner with chemically pure material, after which they were weighed again. By this method the adherence capability of the pure material could be measured and expressed on the basis of weight, volume, or per seed. The data obtained appear in Table 5.

TABLE 5.—ADHERENCE OF RED OXIDE OF COPPER TO TOMATO SEEDS.

LOT NO.	NUMBER OF SEEDS	WEIGHT IN GRAMS				
		Seeds	Seeds+dust	Dust	Dust per seed	Dust per gram of seed
1	1,552	5.3908	5.9496	0.5588	0.000361	0.10366
2	1,668	5.2818	5.8148	0.5330	0.000320	0.10091
3	1,563	5.2310	5.6651	0.4341	0.000278	0.08299
4	1,695	5.7879	6.2652	0.4873	0.000287	0.08419
5	1,758	5.8423	6.3400	0.4977	0.000283	0.08519
Av.	1,647	5.5068	6.0089	0.5022	0.000306	0.09139

Table 5 shows that about 91.4 mgm of chemically pure red oxide of copper will adhere to 1 gram containing about 300 John Baer tomato seeds. This should be compared with 37.4 mgm of copper sulfate monohydrate adhering to the same quantity of a different lot containing about 316 seeds of the same variety (10). Thus, a single

TABLE 6.—COMPARISON OF RED OXIDE WITH BLACK OXIDE OF COPPER AS A SEED TREATMENT FOR COMBATING DAMPING-OFF OF TOMATOES AND EGGPLANTS IN NATURALLY-CONTAMINATED SOIL.

No. of experiment	Date of record	Check (untreated)			Dusted with red oxide of copper					Dusted with black oxide of copper				
		Emergence, per cent	Disease		Emergence, per cent	Disease				Emergence, per cent	Disease			
			Pre-emergence, per cent	Post-emergence, per cent		Pre-emergence		Post-emergence			Pre-emergence		Post-emergence	
						Per cent	Index	Per cent	Index		Per cent	Index	Per cent	Index
						Tomatoes								
1a	Mar. 24,	85.0	15.0	—	98.1	1.9		—		85.2	14.8		—	
1b	1930	79.6	21.4	—	—	—		—		—	—		—	
Av....		82.3	17.7	—	98.1	1.9	10.7	—	—	85.2	14.8	83.6	—	—
2a	Oct. 24,	36.2	63.8	60.0	73.1	26.9		13.5		46.5	53.5		46.0	
2b	1930	41.5	58.5	55.5	73.1	26.9		32.5		44.5	55.5		58.0	
Av....		38.9	61.1	57.8	73.1	26.9	44.0	23.0	39.8	45.5	54.5	89.2	52.0	90.0
3a	Nov. 14,	46.8	53.2	46.5	79.9	20.1		25.0		51.9	48.1		45.5	
3b	1930	45.3	54.7	77.0	79.6	20.4		38.0		43.5	57.5		46.5	
Av....		46.1	53.9	61.8	79.8	20.2	37.5	31.5	51.0	47.7	52.3	97.0	46.0	74.4
4a	Mar. 4,	71.1	28.9	43.0	73.9	26.1		15.0		74.6	26.4		17.5	
4b	1932	69.1	30.9	45.5	81.1	18.9		19.5		71.9	28.1		23.5	
Av....		70.1	29.9	44.3	77.5	22.5	75.3	17.3	39.1	73.3	26.7	89.3	20.5	46.3
Grand Av.		59.4	40.7	54.6	82.1	17.9	41.88	23.9	43.3	62.9	37.1	89.78	39.5	70.23
						Eggplants								
1a	Apr. 27,	39.8	60.2	36.5	52.0	48.0		44.5		54.5	45.5		25.5	
1b	1932	45.2	54.8	28.0	58.1	41.9		40.0		48.2	51.8		33.0	
Av....		42.5	57.5	32.3	55.1	44.9	78.1	42.3	131.0	51.4	48.6	84.5	29.3	90.7

seed weighing 3.34 mgm will hold about 0.31 mgm, or nearly one-tenth of its own weight, of red oxide of copper as contrasted with about 0.12 mgm, or one twenty-fifth of its own weight, of copper sulfate monohydrate. Expressed on the basis of actual copper, each seed holds about 0.27 mgm of copper when dusted with red oxide of copper and only 0.04 mgm of copper when dusted with copper sulfate monohydrate, or an increase of nearly seven times. Thus, the extraordinary adherence of red oxide of copper visually noted is emphasized by quantitative measurements.

COMPARISON OF EFFICIENCIES OF RED AND BLACK OXIDES OF COPPPER

In view of the beneficial increases in stand and reduction in damping-off obtained with red (cuprous) oxide of copper, it seemed of interest to compare it with the black (cupric) oxide of copper. The data, as presented in Table 6, show that the black oxide is almost worthless as a seed treatment fungicide for tomatoes and eggplants. The average stand for the four tomato experiments was 59.4 per cent for the untreated, 82.1 per cent for the red oxide, and only 62.9 per cent for the black oxide of copper. The index of pre-emergence disease as shown in Table 6 was reduced only to 89.78 by the black, whereas, it was reduced to 41.88 by the red oxide of copper—a decrease of nearly one-half. Likewise, the index of post-emergence disease was 70.23 and 43.30, respectively, for the two materials. In one test, however, there was a greater incidence of post-emergence disease on the treated than on the untreated plants. This is an illustration of the way in which damping-off occasionally will take treated seedlings.

Hein (7) remarked that black oxide of copper was useless as a fungicide on potatoes, yet Villedieu and Villedieu (14) reported that it would kill conidia of *Phytophthora infestans*, the organism responsible for late blight. Chaine (4), philosophizing about the work of Villedieu and Villedieu, came to the conclusion that cupric oxide is the active agent in bordeaux and burgundy mixtures and that it acted as a catalyzer in killing the conidia by oxidation. These mixtures as prepared were beneficial in that they produced a greater reacting surface and thus accelerated the catalysis.

MISCELLANEOUS OBSERVATIONS ON RED OXIDE OF COPPER

Altho red oxide of copper has not yet been used as widely as other copper seed treatments for vegetables, it does not appear to be greatly

injurious to those crops tried, including tomatoes, eggplants, peppers, spinach, and cabbage. Furthermore, reports from Niagara County[4] show that it has been used rather successfully on greenhouse-grown celery seedlings which as a rule seem to be rather easily injured by chemicals. In some cases, especially on peppers in Schenectady County, the material was somewhat injurious, not that it killed the seeds, but that it retarded the emergence of the seedlings. Even in such cases, however, the total stand from treated seed was much greater than from untreated seed.

Some observational evidence indicates that high organic matter content, a high moisture content, or both in the soil may offset this injury. Further work along this line is in progress.

The usual observation among growers who have used the material has been that it accelerated emergence and increased the height of the plants over the checks. However, since experience is still lacking in the use of the fungicide over a wide range of conditions, its use by growers should be attended at first with some caution. As yet, there is no way of predicting whether or not injury will follow its use.

Considerable variability among samples of the material has been noted. In all cases for experimental work, the writer has used chemically pure material exhibiting the normal bright red color. One sample of chemically pure material came to hand, however, that was much darker in color than normal. Correspondence with the makers showed that the material had been changing gradually since manufacture from the red to the black oxide. It was thus becoming less and less valuable as a fungicide if the comparative tests between red and black oxide just given are significant.

In one instance that has come to the writer's attention a grower had obtained a dark sample of the technical grade and had found that it was unsatisfactory.[5] It would appear necessary, then, in using the material to make sure that it has the normal bright color, undimmed by age. Several samples of the technical grade examined were much too dark in color to be desirable.

It is of interest in this connection to note that red oxide of copper mixed with lime darkened considerably after a year of storage on

[4]Communication from L. A. Muckle, Farm Bureau Manager.

[5]Communication from Clarence Johnson, Farm Bureau Manager, Schenectady County.

the laboratory shelf, whereas some of the same material mixed at the same time with kaolin seemed not to be dulled in color after the same lapse of time.

The insolubility and adherence qualities of the material suggested it as a possible foliage fungicide that might be substituted for copper-lime dust. Accordingly, the pure material was mixed with lime to make the usual 20–80 formula. This was dusted onto tomatoes, peonies, and lilies in the field during the 1932 season without injury. Weather conditions were such that Botrytis did not develop greatly on the peonies. Although Botrytis was well established on the lilies when the test was begun,[6] yet there was considerable evidence that the dust reduced the subsequent development of the disease. Altho Septoria was not severe on tomatoes, still the red oxide of copper seemed to control the disease almost as well as did 4–4–50 bordeaux mixture. The chemical seemed to adhere well to tomato and lily foliage. In some places the dust on lily leaves was apparent to the naked eye for two weeks after applying in spite of rains that intervened. It also seemed to adhere rather well to tomato foliage. At the present time, the writer is testing in a small way the efficacy of red oxide of copper as a fungicide for controlling bunt of wheat by seed dusting.

APPLICATION OF THE RESULTS OF PRACTISE

Almost without exception practical growers have received the red oxide of copper seed treatment well and have put it to use in their production operations. It seems to have met with favor among greenhouse men in Schenectady County for tomatoes, eggplants, and peppers; in Monroe and Ontario Counties for tomatoes; and in Niagara County for celery.

The material was tested experimentally with the cooperation of spinach growers on muck soils near East Bloomfield, Ontario County, where the resulting stand increases were pleasing to them. The field data on the use of the material on spinach will be presented in a forthcoming publication.

The qualities of the material are such that it has tended already to supplant other copper seed treatments previously recommended for

[6]The writer is indebted to G. L Slate of this Station for aid in dusting the lilies.

damping-off. Altho the material is as good as any for increasing stands, the fact that the copper sulfate soak exceeds it in value for holding up the emerged plants will no doubt militate somewhat against its substitution. It seems especially desirable, however, for smooth-seeded plants.

At the present time, results indicate that red oxide of copper should be used at the rate of 1 pound to 10 pounds of seed or 1½ ounces per pound of seed. The dust should be added to the seed in a tight container and shaken thoroly, so that each seed becomes brick red in color. It is essential that each seed be covered completely with dust because it is the chemical added to the soil with each seed that helps to prevent that seed or the plantlet that it produces from being killed by the fungi in the soil. Whatever the container used, it should not be filled more than half full of seed for the most efficient mixing of the dust.

During the winter of 1932 when the material was first used to any extent commercially, red oxide of copper was difficult to obtain. It was not on a market that was readily available to growers. In general, it was obtained from laboratory supply houses, where, of course, the price was high. Merck and Company, Rahway, N. J., who have kindly furnished some of the experimental material, have agreed to supply a bright red technical grade of red oxide in quantities of 25 pounds or more at 37 cents per pound and for slightly less in larger quantities. Also, K. C. Livermore, Honeoye Falls, N. Y., and the Niagara Sprayer Co., Middleport, N. Y., have agreed to furnish the material in small lots. The names of these dealers are mentioned because of the difficulty that has been experienced in obtaining the fungicide in the open market.

DISCUSSION

There seems to be no question concerning the efficacy of red oxide of copper as a palliative for damping-off of vegetables. The fungicidal properties and adherence qualities of the material recommend it for wider trial where a copper dust fungicide is desired. It has the obvious advantage over a liquid treatment of being dry.

In addition to, or rather a part of, its effectiveness, red oxide of copper has another valuable attribute as a fungicide. As shown in Table 5 it adheres extremely well. This quality of adherence seems

to be fairly permanent, since tomato seed coats that sometimes remain attached to the cotyledons will remain red in color for two or three weeks in spite of all the sprinkling water that may be added.

The acceleration of seedling emergence reported by growers requires careful investigation, because other copper compounds used in these studies have not shown that characteristic; in fact they have tended to retard emergence. The red oxide itself in some localities, notably in Schenectady County, tended to retard emergence somewhat.

A discussion of the possibilities of red oxide of copper as a foliage fungicide, suggested in this paper, must be brief at this stage of the investigation. However, the present copper-lime fungicide used as a dust has one notable weakness--it must be applied to wet foliage before it will adhere effectively. Otherwise, the lime reacts to form carbonates, as shown by Streeter, Mader, and Kokoski (12), and the material is washed away by the first shower. Unfortunately, foliage is seldom wet except at a time of day when most operators are unwilling to apply a fungicide.

As a dust fungicide for foliage, red oxide of copper offers the following advantages: It is insoluble in water to begin with, thus requires no water to make it effective; it seems to adhere well to foliage, thus it may be applied at any time of day when the wind is not high; and as far as is known, it is non-injurious to leaves (tomatoes, lilies, and peonies) at least when diluted with lime.

SUMMARY

1. Red oxide of copper (cuprite) is proposed specifically as a seed treatment fungicide, altho its possibilities as a substitute for copper-lime dust are suggested.

2. Red oxide compared favorably with other copper compounds tried on tomatoes; however, it was somewhat less effective in combating the post-emergence phase of damping-off than the copper sulfate soak. It has been especially desirable as a fungicide for smooth-seeded plants like eggplants, peppers, cabbage, and spinach.

3. Red oxide of copper adhered extraordinarily well to seeds. In fact a single tomato seed will hold about one-tenth of its own weight of the material as compared with only about one-twenty-fifth of its weight of copper sulfate monohydrate.

4. Red oxide of copper may be diluted to one-fourth without altering its fungicidal properties.

5. Black oxide of copper exerted but little fungicidal effect as a seed treatment in these tests, altho it adhered well.

6. Red oxide of copper did not seem to be greatly injurious to seeds, altho this point has not been carefully checked. Some growers report that it accelerates emergence of seedlings. It may deteriorate upon standing, changing to the black form.

7. Red oxide of copper is being tested experimentally as a foliage fungicide on lilies, peonies and tomatoes, and as a seed treatment for bunt of wheat.

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